THE COBALT SERIES; ITS CHARACTER AND ORIGIN[1]

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INTRODUCTION

In that part of northern Ontario and Quebec of which Lake Timiskaming is the geographical center, a series of pre-Cambrian clastic sediments occur which are of peculiar interest to the geologist, not only because they form the country rock of the larger part of the rich silver-bearing veins of the Cobalt mining camp, but because, as is shown in the following pages, their character is such as to indicate that they are entirely of terrestrial origin and have been deposited in part from continental glaciers. If the foregoing conclusion be correct, then another glacial period more ancient than any of those yet described in other parts of the world is added to our knowledge of the geological history of the earth, and positive evidence is afforded as to the remarkable uniformity of geological processes even in pre-Cambrian times.

In order to reach a logical conclusion as to the manner in which any series of rocks has been deposited, full information as to the character and geological relationship of the series as a whole and of all its members is necessary. The following discussion is therefore divided into two parts, in the first of which the geological relations and lithological character of the Cobalt series is described, and in the second, an application is made of those criteria from which the mode of origin of the various members of the series may be inferred.

GEOLOGICAL RELATIONS AND CHARACTER OF THE COBALT SERIES

GENERAL GEOLOGY OF THE TIMISKAMING REGION

Geologically this region belongs to the great Canadian shield of pre-Cambrian rocks which occupies the greater part of north-

[1] Published by permission of the Director of the Geological Survey branch of the Department of Mines, Canada.

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eastern North America, and corresponds in general to the Lake Superior–Lake Huron geological province. In a structural way, the rocks of the Timiskaming region may be divided into three elements which are strikingly differentiated from one another: to the first of these belong the older complex; to the second the Cobalt series (Huronian) and Nipissing (Keweenawan) diabase; and to the third the Pleistocene and Recent deposits.

The first subdivision, the older complex, consists of two classes of rocks: (1) the surficial, consisting of basic to acid volcanic flows, conglomerate, greywacke, arkose, and slate; and (2) the plutonic, consisting of granite, granodiorite, diorite, and related rocks. The rocks of the second class, as far as has been observed, are intrusive into the surficial class although the presence of pebbles and bowlders of granite in the conglomerate shows conclusively that an older granite occurs somewhere in the region and that a great erosion interval is represented.

From an examination of a general geological map of northeastern Canada, it may be seen that a wide belt of granite and related rocks (Laurentian) extends continuously from Georgian Bay to the Gulf of St. Lawrence, while to the north of this, there is a belt in which rocks of the surficial class predominate and which extends from the north shore of Lake Huron to Lake Mistassini. It seems probable that the southern granitic belt represents an ancient geanticlinal mountain core and the adjacent belt on the north a geosynclinal intermontane belt, but denudation proceeded so far in pre-Cambrian times that this synclinorium was cut off close to its base so that the surficial members of the complex are intruded by numerous small isolated batholiths of granitic rocks which have effected marked local changes in the structural trend of the rocks in their vicinity.

On the profoundly denuded surface of this ancient complex lies the second structural element, the Cobalt series (Huronian). In striking contrast with the complicated plications of the older element, the structure of these rocks is comparatively simple. They have been very slightly folded into broad, gently pitching anticlines and synclines, the dip being usually less than 20 degrees.

Along with the older complex the Cobalt series is intruded by the Nipissing (Keweenawan?) diabase which took the form of dikes in the older basement but spread out as sills in the flat-lying Huronian sediments.

The third structural subdivision, the Pleistocene and Recent deposits consist of gravel, sand, and bowlders, in the various forms assumed by glacial and fluvioglacial materials, and stratified clay and sand of postglacial lacustrine origin. These rest on the beveled surface of the Cobalt series or on the truncated surface of the older complex from which the Cobalt series has been stripped away.

THE COBALT SERIES

GENERAL CHARACTER AND SUBDIVISIONS

The Cobalt series consist of an assemblage of clastic sediments, conglomerate, greywacke, argillite,[1] arkose, and quartzite. These rocks are not sharply defined members, for they not only pass gradationally into one another, both horizontally and vertically, but conglomerate commonly occurs in the midst of greywacke or greywacke in the midst of conglomerate, and a similar relationship may exist between all the members of the series. Nevertheless, in a general way, there is a succession in most localities, from a basal conglomerate through greywacke and argillite to arkose, which in turn is overlain by an upper conglomerate.

A compilation of all the published observations of the succession and thickness of the various rocks comprising the series throughout the Timiskaming region is given in the accompanying table. Many of these sections are evidently only partial, including in some cases the upper members and in others the middle or lower. It can be seen, however, that there is generally an upper and lower conglomerate with greywacke and argillite, quartzite, and arkose as intermediate members.

[1] At the suggestion of Dr. L. V. Pirsson, the term argillite is here redefined to designate a fine grained slate-like rock which has been very firmly cemented but has no slaty cleavage. Its position in the mud-slate series corresponds very closely to that of quartzite in the sand-sandstone group.

SECTIONS OF THE COBALT SERIES IN THE TIMISKAMING REGION, ONT. AND QUE.*

Rock	Thickness	Locality	Reference
Quartzite, etc.....	1,100 feet	Timiskaming district	A. E. Barlow, *Rep. Can. Geol. Surv.*, X (1897), 104.
Slate and greywacke	100 "		
Conglomerate.....	600 "		
Slate†.....	?	Between Rabbit and Timagami lakes	G. A. Young, *Sum. Rep. Can. Geol. Surv.* (1904), p. 198.
Conglomerate.....	?		
Conglomerate.....	?	Cobalt, Ont.	W. A. Parks, *Sum. Rep. Can. Geol. Surv.* (1904) p. 211.
Quartzite.....	?		
Quartzite, etc.....	90 "	Windigo Lake	W. A. Parks, *ibid.*, p. 215.
Slate† and greywacke	90 "		
Conglomerate.....	100 "	Mount Shiminis	W. A. Parks, *ibid.*, p. 220.
Quartzite.....	135 "		
Slate†.....	315 "		
Conglomerate.....	?	Cobalt, Ont.	W. G. Miller, *Ann. Rep. Bur. Mines, Ont.* (1905), Pt. 2, p. 34.
Quartzite.....	?		
Greywacke.....	?		
Conglomerate.....	?		
Conglomerate.....	?	Larder Lake, Ont.	R. W. Brock, *ibid.*, (1907), p. 211.
Quartzite.....	?		
Slate†.....	?		
Quartzite.....	?		
Conglomerate.....	?		
Conglomerate.....	?	Claims H.R. 34 and 163 South Lorain.	A. G. Burrows, *ibid.* (1908), Pt. 2, p. 24.
Greywacke and slate†	?		
Slate†.....	?	Everett Lake Gowganda dist.	A. G. Burrows, *ibid.*, p. 10.
Quartzite.....	?		
Conglomerate.....	?		
Conglomerate.....	?	Bloom Lake	A. G. Burrows, *ibid.*
Slate†.....	?		
Conglomerate, etc....	?	Gowganda dist.	W. H. Collins, *Prelim. Rep. on Gowganda Dist.*, pp. 26 and 27; *Geol., Surv., Dept. of Mines, Can.* (1909.)
Greywacke quartzite	?		
Conglomerate.....	200+"		
Greywacke arkose,etc.	?	Montreal river district	W. H. Collins, *Sum. Rep. Geol. Surv., Dept. of Mines* (1910), p. 199.
Conglomerate.....	?		
Conglomerate.....	750 "	Kekeko hills Pontiac County, Que.	M. E. Wilson, *Prel. Mem. on Abitibi Dist., Que.*

* Sections are in descending order.

† The term slate is used for a slate-like rock without slaty cleavage—argillite.

SECTIONS OF THE COBALT SERIES IN THE TIMISKAMING REGION, ONT., AND QUE.—*Continued*

Rock	Thickness	Locality	Reference
Arkose.....	220 "	North end Lake Opasatika, Pontiac Co., Que.	M. E. Wilson, *ibid.*
Conglomerate.....	80 "		
Arkose.....	250 "	Swinging Hills, Pontiac Co., Que.	M. E. Wilson, *ibid.*
?	365 "		
Conglomerate.....	70+"		
Conglomerate.....	65 "	Labyrinthe Hills Pontiac Co., Que.	M. E. Wilson, *ibid.*
Arkose.....	165 "		
?	175 "		

Basal conglomerate.—Wherever the Cobalt series is seen in contact with the rocks of the older complex, the basal member of the series is usually a conglomerate. The outstanding feature of this basal conglomerate is its heterogeneity, not only in the size and angularity of the included fragments, but in the variability of the rock, both in texture and composition from point to point. In some places it is largely composed of coarse fragmental material with little matrix and, in other places, consists largely of matrix with few fragments. As a rule it is unstratified, but locally a partial alignment of the pebbles can be seen.

The matrix of the conglomerate varies greatly in texture and composition and may be either coarse and feldspathic or exceedingly fine grained and slate-like in appearance; the coarser types are, however, by far the most common. Examined under the microscope the matrix is seen to be composed of angular, subangular, and round fragments of quartz, feldspar, quartz porphyry, mica schist, rhyolite, andesite, basalt, and other rocks inclosed in a cement consisting chiefly of chlorite, but usually accompanied by small quantities of carbonate, epidote and pyrite (Figs. 1 and 2).

The pebbles and bowlders of the conglomerate include, even in a single rock exposure, nearly every variety of rock occurring in the older complex. Fragments of granite occur everywhere, and are commonly many miles from the nearest occurrence of this rock in the underlying basement from which the Cobalt series was evidently derived. As is generally characteristic of coarsely

clastic sediments of this character, the pebbles and bowlders are commonly subangular or angular in shape though round fragments are also present.

Greywacke and argillite.—The basal conglomerate of the Cobalt series commonly passes gradually upward by the loss of its pebbles and bowlders into greywacke and argillite. This greywacke was originally a ferromagnesian sand and the argillite a ferromagnesian mud, both of which are now, however, very firmly cemented, the

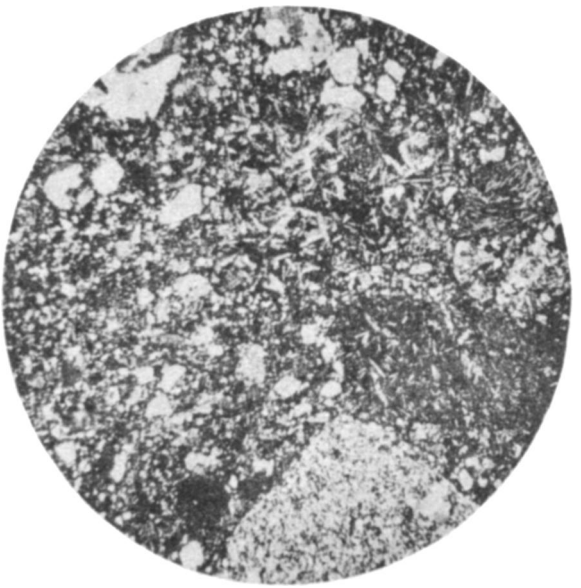

FIG. 1.—Photomicrograph of conglomerate matrix. Ordinary light. ×20

argillite resembling a slate but differing from a slate in possessing no slaty cleavage. The greywacke and argillite, like the other members of the Cobalt series, vary greatly, and here and there contain beds of arkose, masses of conglomerate, and, in some places, single isolated bowlders. In a few places the greywacke is unstratified, but as a rule both it and the argillite are uniformly bedded. The microscopic examination of the greywacke shows it to consist of fragments of quartz, feldspar, basalt, andesite, and other ferromagnesian rocks along with an abundance of chlorite.

The argillite is much finer grained than the greywacke, consisting of exceedingly minute fragments of quartz and feldspar imbedded in a chloritic cement. Small quantities of sericite, epidote, and carbonate are also commonly present in all of these rocks.

Arkose and quartzite.—The greywacke and argillite are usually replaced on passing upward by arkose or quartzite, the transition taking place by a gradual increase in the feldspar and quartz content or by an alteration of beds of the two rocks. The arkose

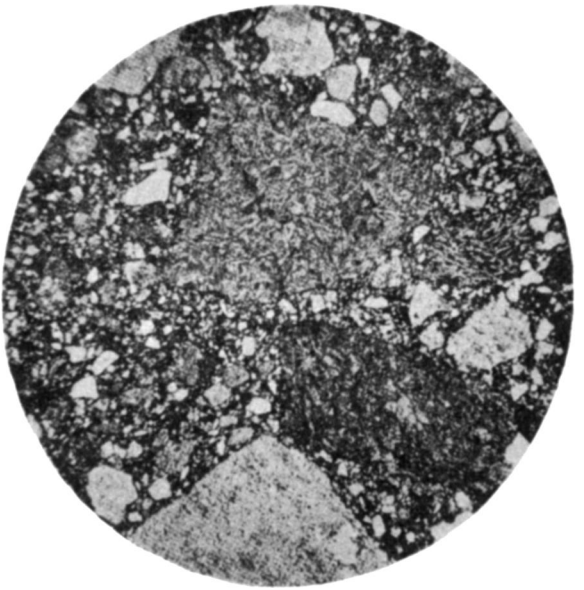

FIG. 2.—Photomicrograph of conglomerate matrix. Crossed nicols. ×20

and quartzite are firmly cemented sands which, when examined under the microscope, are found to consist of round, angular, or subangular fragments of quartz, or of quartz and feldspar along with small quantities of calcite, sericite, epidote, pyrite, and other minerals. They are generally stratified, may show ripple marks, are locally cross-bedded, and in places contain well-rounded pebbles of quartz and jasper in lenticular aggregations.

Upper conglomerate.—Wherever the Cobalt series has a considerable vertical thickness, the arkose and quartzite are overlain

conformably by an upper conglomerate which differs in no respect from the lower member of the series and cannot be distinguished from it except where the stratigraphical succession is known.

INTERFORMATIONAL UNCONFORMITIES

In his geological report on the Cobalt district, W. G. Miller subdivided the Cobalt series into Lower and Middle Huronian,[1] but more recently[2] has adopted the name Cobalt series to include both these subdivisions. Miller's classification of the Huronian into two series was based on an unconformity between greywacke and arkose occurring, on lot 4, in the twelfth concession of Lorrain Township, Nipissing district, Ontario, where angular fragments of the greywacke are inclosed in an arkose matrix. Unconformities between a "greywacke conglomerate and an overlying arkose series" are also mentioned by A. G. Burrows in a marginal note on a map of "part of the Gowganda silver area," published by the Ontario Bureau of Mines, but no details as to the character of these are given. In one locality in the Larder Lake district the writer observed an arkose bed to contain fragments of an underlying argillite, but the fragments were irregular in outline and contained sand grains along their margin as if the argillite had been plastic at the time of its fragmentation. Fragments of a precisely similar character and in the same relationship have also been observed by W. H. Collins in the region north of the Sudbury district.[3] With the foregoing exceptions, as far as has been observed, the various members of the series are in conformable relationship to one another[4] so that the unconformities that have been described are local and probably interformational in character and do not necessarily signify a break of any importance in the continuity of deposition.

DISTRIBUTION OF COBALT SERIES

The Cobalt series is now known to occur in the Timiskaming region and vicinity throughout an area of approximately 20,000

[1] *Ann. Rep. Bur. of Mines, Ont.* (1905), Pt. 2, pp. 40–42.

[2] *Eng. Min. Jour.*, XCII (1911), 648.

[3] Personal communication.

[4] *Sum. Rep. Geol. Surv., Dept. of Mines, Can.* (1906), p. 117; "Geol. of an Area Adjoining the East Side of Lake Timiskaming," *Geol. Surv., Dept. of Mines, Can.* (1910), p. 30; "Prel. Rep. on Gowganda Mining Division," *ibid.* (1909), p. 32.

square miles, but this is probably a mere fraction of its former extent for much Huronian, having the same lithological character and geological relationships, occurs in outlying districts such as that on Lake Chibougamau, about 300 miles to the northeastward.

THE PRE-COBALT SERIES PALEOPLAIN

Since the rocks comprising the Cobalt series have been but very gently folded, it follows that the surface upon which they were deposited has also not been greatly deformed, and that by the study of the contours of the contact of the basal conglomerate and the older complex, the stage, in physiographic development of the ancient erosion surface, at the time the deposition of the Cobalt series began, may be deciphered. The approximately uniform elevation, at which the junction of the Cobalt series and the older complex occurs throughout considerable areas, shows that the topography of the ancient surface was generally flat, but here and there hills consisting of rocks of the older complex occur which rise to elevations of 200 to 600 feet above the surrounding country and which must have had a still higher elevation prior to the deposition of the Cobalt series, for they have undergone denudation since that series was stripped from their surface. The ancient surface had therefore a range in elevation as great or greater than that of the region at present, but on the whole was probably more flat, the hills being local remnants which rose above the general level of erosion. This pre-Cambrian surface of denudation, therefore, represents a peneplain buried and later exposed and falls into the class of form known as a paleoplain.

THE CONTACT OF THE COBALT SERIES AND THE OLDER COMPLEX

The contact between the Cobalt series and the rocks of the older complex is peculiar in places, in that no definite line of junction can be seen, the underlying rock passing gradually upward into the basal conglomerate; in other places, however, the contact is very sharply defined, the conglomerate resting on a smoothly denuded surface. A striking example of this transitional relationship occurring at Baie des bères on the east shore of Lake Timiskaming has been described in detail by Barlow

and Ferrier.[1] Examples of the sharply defined contacts have been described by W. H. Collins and by the writer.[2]

THE ORIGIN OF THE COBALT SERIES

HYPOTHESES PROPOSED

The Cobalt series has, in recent years, been the object of special study by those geologists engaged in fieldwork in the Timiskaming region for the purpose of procuring evidence which would confirm or disprove the glacial hypothesis which has been strongly advocated by A. P. Coleman in a number of recent publications.[3] With this object in view, the writer, while in the field, paid special attention to those characteristics of the various members of the series which might have a bearing on the conditions under which they were deposited, hoping in that way to reach some definite conclusions as to their origin.

That the conditions under which the series was deposited were unusual is indicated by the various modes of origin which have been suggested from time to time, by the geologists who have studied these rocks in the field. Owing to the fact that the earlier geologists did not distinguish the Cobalt series from the underlying Abitibi group[4] (Keewatin), the conglomerate was thought to be closely related to the lavas of the underlying basement and were said to be of pyroclastic origin,[5] although it was noted that many fragments of granite and other plutonic rocks were present. In 1905, A. P. Coleman in his report[6] on the Sudbury nickel field,

[1] "On the Relations and Structures of Certain Granites and Associated Arkoses on Lake Timiskaming, Canada," *Rep. B.A.A.S.*, Toronto (1897), pp. 656–60; *Ann. Rep. Geol. Surv. Can.* (1897), pp. 195–99, 1.

[2] "Prel. Rep. on Gowganda District, Ont." *Geol. Surv. Bran., Dept. of Mines, Can.* (1909), p. 31; "The Larder Lake District, Ont., and Adjoining Portions of Pontiac County, Que." *Mem. 17, Geol. Surv., Dept. of Mines, Can.*, 1910.

[3] *Amer. Jour. Sci.*, XXIII, 187–92; *Bull. Geol. Soc. Amer.*, XIX, 347–66; *Jour. Geol.*, XVI, 149–58.

[4] The name Abitibi group is here used for those surficial rocks of the older complex occurring in the Timiskaming region, whose stratigraphical and structural relations are as yet unknown.

[5] *Ann. Rep., Can. Geol. Surv.*, X (1897), 96.

[6] *Ann. Rep. Bur. of Mines, Ont.*, XIV (1905), Pt. 3, p. 1289.

pointed out the resemblance of a greywacke conglomerate, occurring in the vicinity of Ramsay Lake, to bowlder clay; and in the same year, W. G. Miller mentioned the possibility of a glacial origin for the conglomerate of the Cobalt series, but also suggested desert conditions of deposition in the following quotation. "The writer is not able to offer a satisfactory explanation for the character of the sediments found in some of these strata. . . . . To account for the undecomposed and angular character of much of the fragmental material, the writer is inclined to the belief that desert conditions prevailed in this region at the time some of the middle Huronian rocks, at least, were formed."[1] R. W. Brock in his report on the Larder Lake District published in 1907,[2] noted some characteristics of the rocks favorable to the glacial hypothesis but concluded that there were still difficulties in the way of its acceptance. He also observed that many of the included fragments had the form of bowlders worn by river sands.

APPLICATION OF CRITERIA

Although the various suggestions in the above quotations all imply a continental origin, none of these writers have pointed out the many characteristics of the series which point to terrestrial conditions of deposition. The great heterogeneity and general absence of complete sorting throughout the greater part of the series, the presence of ripple marks, current marks, cross-bedding, and interformational unconformities, the presence of an ancient soil at the base of the conglomerate in places, the angularity or subangularity of the fragmental material comprising the series, and the great thickness and enormous extent of the conglomerate are features distinctly characteristic of land sediments. It shall therefore be assumed without further discussion that the Cobalt series is of terrestrial origin, the term terrestrial implying deposition on the land in contrast with deposition in the sea or on the seashore.

Continental clastic sediments may be formed by volcanic action or by weathering, creepage, lakes, rivers, winds, or glaciers,

[1] *Ann. Rep. Bur. of Mines, Ont.* (1905), Pt. 2, p. 41.

[2] *Ibid.*, XVI (1907), 212.

the degree of importance and relationship of the latter agencies to one another depending, in part, on climate, and in part, on the topography of the land.[1]

In the following discussion I shall apply some of the criteria which characterize sediments originating in these various ways to the different members of the Cobalt series, and in that way attempt to reach some conclusions as to the climate and conditions of deposition prevailing during this Huronian period.

1. *Pyroclastic origin.*—Owing to the misunderstanding of the relationship of the Huronian of the Timiskaming region to the volcanic rocks of the older complex, the conglomerate of the Cobalt series was at one time thought to be of pyroclastic origin but it is now known that it is almost, if not entirely,[2] composed of material derived from the underlying floor. This mode of origin need not therefore be considered.

2. *Weathering and creepage.*—Since weathering and creepage are closely related processes operating together, for the purpose of this discussion they may be considered as one.

The indefinite contacts which occur at the base of the Cobalt series, in places, indicate that at the time the deposition of the series was initiated, the surface of the ancient complex was covered by a considerable thickness of soil and that this has been preserved so that the basal beds of the conglomerate at these points represent a fossil regolith, developed *in situ* by weathering.

This ancient soil consisted of disaggregated, undecomposed rock fragments, a feature from which some inference may be drawn as to the climate prevailing at the time it was formed. The domination of disintegration over chemical decomposition, on the earth's surface today, is characteristic of regions[3] of youthful topography, is also characteristic of arid climates[4] and to a lesser extent of cold

[1] J. Barrell, *Jour. Geol.*, XVI (1908), 159; A. Penck, *Amer. Jour. Sci.*, XIX (1905), 166.

[2] *Ann. Rep. Bur. of Mines* (1905), Pt. 2, p. 47.

[3] B. Willis, *Jour. Geol.*, I (1893), 477.

[4] E. Pumpelly, *Geol. Soc. Amer.*, XVI (1908), 167; J. Barrell, *Jour. Geol.*, XVI (1908), 167.

or temperate climates,[1] but is not characteristic of warm humid climates.[2] Since this region, at the time the soil was formed, was practically a peneplain, the topographic factor may be eliminated. If it be assumed, therefore, that the variations in the conditions for soil development were the same in pre-Cambrian times as at present, the climate which preceded the deposition of the Cobalt series was either cold and humid, temperate and humid, or arid.

It is possible that owing to the absence of abundant vegetation to supply carbon dioxide to the ground water, or because of differences in the composition of the atmosphere, the relationship of the chemical decay in the soil to climate may have been somewhat different at that early period, but it is doubtful whether this would be of sufficient importance to modify the foregoing conclusion. The abundance of limestone in some of the early pre-Cambrian formations indicates that carbon dioxide was certainly present in the atmosphere at the very beginning of geological time and may have been more abundant than in later periods, for it seems probable that the loss of carbon dioxide from the atmosphere through the formation of limestone and coal beds, since the pre-Cambrian, has been greater than the additions from other sources.

3. *Lacustrine deposition.*—The uniformly stratified argillite, greywacke, arkose, and quartzite which form a considerable part of the Cobalt series were evidently deposited from standing bodies of water and are therefore flood-plain or lacustrine deposits. However, from the general greenish-grey or green color of all these sediments, from the absence as far as has been observed of mud cracks, rain prints, or other evidence of exposure to the air,[3] in even the fine grained argillite, and from the presence of uniformly continuous ripple marks in the quartzite, it seems safe to conclude that these deposits have not been laid down from either flooded rivers or ephemeral lakes, but were deposited from permanent bodies of water which persisted from year to year.

[1] I. C. Russell, *Bull. 52, U.S. Geol. Surv.* (1888), p. 12; G. P. Merrill, *Bull. Geol. Soc. Amer.*, VI (1895), 321–22.

[2] E. W. Hilgard, *Soil* (1906), 398–417.

[3] J. Barrell, *Jour. Geol.*, XVI (1906), 538; J. Walther, *Einleitung in die Geologie* (1897), p. 846.

With regard to the characteristics of these sediments which have a climatic significance, it may be observed from the features mentioned in the previous paragraph, that these, in general, point to humid rather than to arid or semiarid conditions of deposition. Furthermore, bowlders occur in places in the midst[1] of fine grained, stratified greywacke and argillite, a condition which seems to necessitate the presence of floating ice. From this, it may be inferred that the climate of this period was not only humid but cold.

4. *Aeolian deposition.*—Since the greater part of the finer grained material comprising the Cobalt series is uniformly bedded, it is evident that these are subaqueous deposits. Moreover it was pointed out in the previous paragraph that the climate, at the time these materials were laid down, was probably cold and humid. Consequently it may be inferred that aeolian action was never a depositional factor and probably played little or no part in the formation of the series.

5. *Fluviatile deposition.*—The general great heterogeneity of the conglomerate of the Cobalt series, the great variability in the matrix, in the size of the pebbles, and bowlders, and in the rock types represented in the conglomerate, the varying degree of abrasion to which the pebbles and bowlders of the conglomerates have been subjected, the presence of cross-bedding in places are all characteristics commonly pertaining to sediments of a fluviatile origin which have been deposited not far from the source of supply. The conglomerates of the Cobalt series have therefore the essential characteristics of fluviatile deposits.[2]

Notwithstanding, however, the apparent similarity of the conglomerates of the Cobalt series to river deposits, there are some features associated with these which are inconsistent with a fluviatile origin. A considerable part of the bowlders contained in the conglomerate, in places, are 2, 3, or even 8 feet in diameter[3] and are commonly many miles from the nearest occurrence of similar rocks in the older complex. Moreover, the surface upon which

[1] A. B. Coleman, *Jour. Geol.*, XIV (1908), 153.

[2] C. R. Mansfield, *Jour. Geol.*, XV (1907), 550–55.

[3] *Jour. Geol.*, XVI (1908), 151; "Prel. Rep. Gowganda Min. Div.," *Geol. Surv., Dept. of Mines, Can.* (1909), p. 27.

the conglomerate was deposited was one of mature topography, so that the transportation of the large bowlders must have been effected by streams having gentle gradients. In order to explain this difficulty, it has been pointed out[1] that the climate of this Huronian period may have been semiarid and that during floods in regions where such climatic conditions prevail, bowlders of

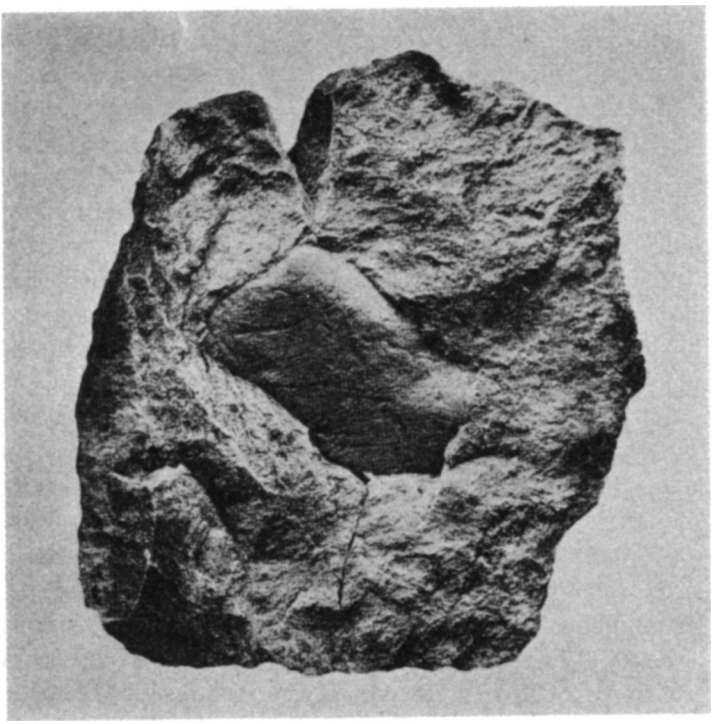

FIG. 3.—Scratched and faceted pebble from the conglomerate of the Cobalt series, occurring in Boischatel Township, Pontiac County, Quebec—a point about 60 miles northeast of the Cobalt district.

large size may be transported long distances by rivers. But it has already been shown from the character of the greywacke, argillite, arkose, and quartzite associated with the conglomerate, that the climate at the time these rocks were deposited was certainly not arid and was probably humid and cold. Furthermore,

[1] *Ann. Rep. Bur. of Mines, Ont.*, XIV (1905), Pt. 2, p. 47.

the green or greenish-gray color which is everywhere characteristic of the conglomerate is not the color which usually distinguishes more recent fluviatile gravels developed in arid or semiarid regions, so that unless the pre-Cambrian atmosphere was deficient in oxygen this feature also points to humid climatic conditions. Fluviatile conglomerates of the coarse unsorted types which are characteristic of the Cobalt series are limited on the earth's surface at present to regions of youthful topography or arid climates.[1] These factors, usually operating together, have resulted in the building up of immense accumulations of river gravels on piedmont slopes and in interior basins. If it be assumed, therefore, that the conglomerates of the Cobalt series are of fluviatile origin, this conclusion must be reached in the face of the facts that these immense deposits covering a minimum area of 20,000 square miles were built up in a region having a low relief and a pluvial climate, conditions which in every particular are the reverse of those under which similar fluviatile deposits are accumulating on the earth today.

6. *Glacial deposition.*—In a number of papers published within the last few years, A. P. Coleman has advocated the glacial origin of the conglomerates of the Cobalt series, pointing out their striking similarity to the Pleistocene glacial deposits and to similar rocks in other parts of the world to which a glacial origin has been assigned. The principal features emphasized by Coleman are the resemblance of the matrix of the conglomerate to bowlder clay; the enormous extent and great thickness of the conglomerate; the occurrence of immense bowlders at a distance of several miles from the source of supply; the great size, angularity and variety of the pebbles and bowlders of the conglomerate; and, finally, the finding of scratched and "soled" pebbles and bowlders in the conglomerate at Cobalt, Ont.[2]

[1] Medlicott and Blanford, *Geology of India*, p. 397; Huntington, *Carnegie Inst. Exploration in Turkestan*, p. 40; J. Barrell, *Jour. Geol.*, XIV (1906), 330; A. C. Trowbridge, *ibid.*, XIX (1911), 738; E. W. Hilgarde, *Sci.*, N.S., XV (1902), 414; N. S. Shaler, *Bull. Geol. Soc. Amer.*, XII (1907), 271–300; I. C. Russell, *Geol. Mag.*, VI (1886), 289–95; J. L. Rich, *Jour. Sci.*, XVIII (1910), 601–32.

[2] *Amer. Jour. Sci.*, XXIII (1907), 187–92; *Jour. Geol.*, XVI (1908), 149–58; *Bull. Geol. Soc. Amer.*, XIX (1908), 347–466.

As opposed to the glacial hypothesis, it has been maintained that glaciated surfaces should somewhere be found beneath the basal conglomerate instead of the ancient regolith which is commonly present.[1] In reply to this objection, Coleman has pointed out that "near the edge of a glaciated area where the thickness of ice is not great, the ice sheet often moves for many miles over loose material without ever reaching the rock surface beneath," and that this condition existed over thousands of square miles in certain parts of the United States during the Pleistocene continental glacial epoch and also throughout a large part of the area covered by carboniferous bowlder clay in India.[2] It must, furthermore, be recalled that the number of points at which the junction of the Cobalt series and the underlying basement has been examined is not great and that, at some of these, the contact is sharply defined, the conglomerate resting on a smoothly eroded surface. The latter might well be glaciated surfaces, although stream erosion or wave action might no doubt produce a similar effect.

Owing to the firmly cemented character of the conglomerates of the Cobalt series, it is difficult to separate the pebbles and bowlders from their matrix, but during the summer of 1911 an exceptionally favorable locality was found at the eastern end of the Kekeko Hills in Boischatel Township, Que., where Mr. E. M. Burwash, who assisted the writer in the field, succeeded in breaking out some pebbles from the conglomerate which were definitely scratched in several directions (Fig. 3). The conglomerate at this point lies almost horizontal and has been neither mashed nor faulted, so that the scratches cannot be attributed to dynamic action.[3] The pebbles exhibiting the scratches consist of fine grained greenstone and possess the typical rounded corners and faceted faces of glacial stones.

In order to obtain further definite evidence bearing on the glacial origin of the Cobalt series, an attempt was made to count the "soled" pebbles and bowlders in the conglomerates. Only those stones having rounded corners and two or more plane faces,

[1] *Ann. Rep. Bur. of Mines, Ont.*, Pt. 2, p. 58; *Can. Min. Jour.*, XXX, 646–97.

[2] *Jour. Geol.*, XIV (1908), 155; *Can. Min. Jour.*, XXX, 694.

[3] *Ann. Rep. Bur. of Mines, Ont.* (1907), Pt. 2, p. 58.

which, when projected, intersected at a considerable angle, were counted, but since it was not possible to break out the pebbles and bowlders for examination on all sides, the count was made from observation of the outlines exhibited in a given area of rock surface. The results obtained were as follows:

Total Number of Pebbles and Bowlders	Number of Soled Pebbles and Bowlders	Percentage	Locality
205	17	8	Destor Township, Pontiac Co., Que.
210	37	18	Kekeko Hills, Boischatel Township, Pontiac Co., Que.
99	38	38	Labyrinthe River, Dasserat Township, Pontiac Co., Que.
168	54	26	Labyrinthe Hills, Dasserat Township, Pontiac Co., Que.
200	60	30	N. shore Larder Lake, Hearst Township, Nipissing District, Ont.

If it had been possible to break out the pebbles and bowlders and observe them in three dimensions instead of one, the above percentages would certainly be greatly increased.

In the preceding discussion of the glacial hypothesis, attention has been confined to the conglomerates of the series. One of the strongest arguments, however, in favor of Huronian continental glaciation is to be found in a comparison of the series as a whole, to the Pleistocene glacial, fluvioglacial, and postglacial deposits of the same region—for each of these has its exact counterpart in the Cobalt series. At the base of the latter, there is the conglomerate, which, like the Pleistocene glacial drift, is exceedingly variable in thickness, and like the drift is unstratified, in part, resembling till, is rudely sorted and cross-bedded, in part, similar to the fluvioglacial deposits of kames, eskers, and outwash plains, and, in places, passes into unstratified greywacke containing scattered pebbles and bowlders, thus duplicating bowlder clay.[1] Overlying the basal conglomerate, there is the stratified greywacke, argillite, arkose, and quartzite which have their parallel in the Pleistocene postglacial stratified clay and sand of lacustrine

[1] "Prel. Rep. on Gowganda Dist.," *Geol. Surv., Dept. of Mines* (1909), p. 26.

origin.[1] In both of these deposits, bowlders have been found which have been attributed to floating ice.[2] The Cobalt series differs from the Pleistocene deposits of northern Ontario and Quebec in the greater thickness of arkose and quartzite which it contains and in the presence of an upper conglomerate[3] overlying the finer grained members of the series. These conditions, however, would simply imply that the lake which covered the region subsequent to the deposition of the basal conglomerate was of longer duration than that of the Pleistocene, and that following the lacustrine epoch a second continental ice sheet advanced over the region from which an upper conglomerate was laid down. If it be assumed, therefore, that the conglomerates of the Cobalt series are of glacial origin, then there are at least two till sheets present, and the stratified greywacke, argillite, quartzite, and arkose constitute interglacial deposits.

The essential similarity of the greywacke and argillite of the Cobalt series to the postglacial lacustrine clays of the region is shown in the following table of chemical analyses. Column I is an analysis of the argillite and column II that of the stratified clay

	I	II	III	IV	V
SiO_2	62.74	52.00	64.81	57.94	61.54
Al_2O_3	16.94	16.11	17.48	17.92	.....
Fe_2O_3	5.07	4.69	5.23	5.83	.....
FeO	1.59		1.64		
MgO	3.05	4.10	3.14	4.56	.....
CaO	1.39	8.26	1.43	9.20	.84
Na_2O	6.07	2.76	6.27	3.09	4.73
K_2O		1.74		1.95	2.84
H_2O-	.36	9.64	.....	.....	.....
$HO+$	3.20	.....	.....	.....	.....
SO_3	.....	.09	.....	.10	.....

I. *Ann. Rep. Bur. of Mines, Ont.*, XIV (1905), Pt. 2, p. 48.
II. *Ibid.* (1905), p. 33.
III. I recalculated to a total of 100 omitting water.
IV. II recalculated to a total of 100 omitting water.
V. *Jour. Geol.*, XVIII (1910), 669.

[1] *Ann. Rep. Bur. of Mines, Ont.*, XIV (1905), Pt. 2, p. 33; XVIII (1908), 282, 284; *Sum. Rep. Geol. Surv., Dept. of Mines, Can.*, 1911.

[2] *Jour. Geol.*, XVI (1908), 153; *Ann. Rep. Bur. of Mines, Ont.*, XX (1911), Pt. 1, p. 220.

[3] See table, pp. 124, 125.

occurring at the north end of Lake Timiskaming. In order to make these more nearly comparable, they have been recalculated to a total of 100 omitting the water. In Column V a partial analysis of argillite from Lily Lake in the Gowganda district, is inserted.

It will be observed that in both the argillite and the clay there is an excess of soda over potash, a relationship which is usually reversed in normal sediments of the slate-shale series. The large percentage of lime and magnesia in the postglacial lacustrine deposits is undoubtedly due to the large amounts of Paleozoic limestone which were denuded away by the Pleistocene continental ice sheets and were thus transformed into glacial drift and later redeposited as stratified clay.

CONCLUSION

Having assembled the evidence which might have a bearing on the origin of the Cobalt series, the following conclusions may be cited with regard to the climatic conditions and depositional processes in operation at the time these sediments were laid down: (1) that the series is of terrestrial origin; (2) that the basal portion of the series is in places an ancient regolith; (3) that the stratified greywacke, argillite, quartzite, and arkose are lacustrine deposits; (4) that aeolian deposits are not represented in the series; (5) that the climate of this period was *not* arid or semiarid and was probably cold and humid. (6) With regard to the mode of deposition of the major part of the conglomerate only two hypotheses need be considered. They are either of fluviatile origin or have been deposited from continental ice sheets. From a consideration, however, of the difficulties of transportation involved in the fluviatile hypothesis and that the climate and topography of the region were wholly the reverse of those under which fluviatile deposits of this character are accumulating on the earth today, and on the other hand, the facts that practically every feature of the Cobalt series has its duplicate in the Pleistocene glacial, interglacial, or postglacial deposits of North America, that the pebbles and bowlders of the conglomerates have a characteristically "soled" appearance and that striated pebbles and bowlders have been found in two localities over 60 miles apart, it seems necessary to

conclude that the evidence preponderates in favor of the hypothesis that the conglomerates of the Cobalt series were deposited from pre-Cambrian continental ice sheets.

In the above pages an attempt has been made to apply the criteria which distinguish the various types of continental clastic sediments to the different rock types represented in the Cobalt series and thereby to reach a definite conclusion with regard to their origin. As a result it has been shown that not only has every variation in the series its duplicate in the glacial, interglacial, or postglacial deposits laid down in association with the Pleistocene continental ice sheets of the same region, but that no other known depositional process will so well account for all the many peculiarities and associations of sediments found in the series as the glacial hypothesis. Furthermore, the objection that striated surfaces have not been found beneath the basal conglomerate loses much of its force when it is recalled that only an exceedingly small part of the contact between the Cobalt series and the older complex has been observed, that the underlying surface in some places has been smoothly eroded, and that the presence of the overlying conglomerate at those points generally makes an examination for striae impracticable.

With the progress of detailed geological investigation in regions where pre-Cambrian rocks occur, evidence is accumulating which indicates that the processes at work on the earth's surface today were in operation in the very earliest pre-Cambrian periods. The existence of pre-Cambrian continental ice sheets would therefore be simply another link in the chain of evidence pointing to the uniformity of natural processes from the very earliest time in the earth's history of which we have any knowledge.